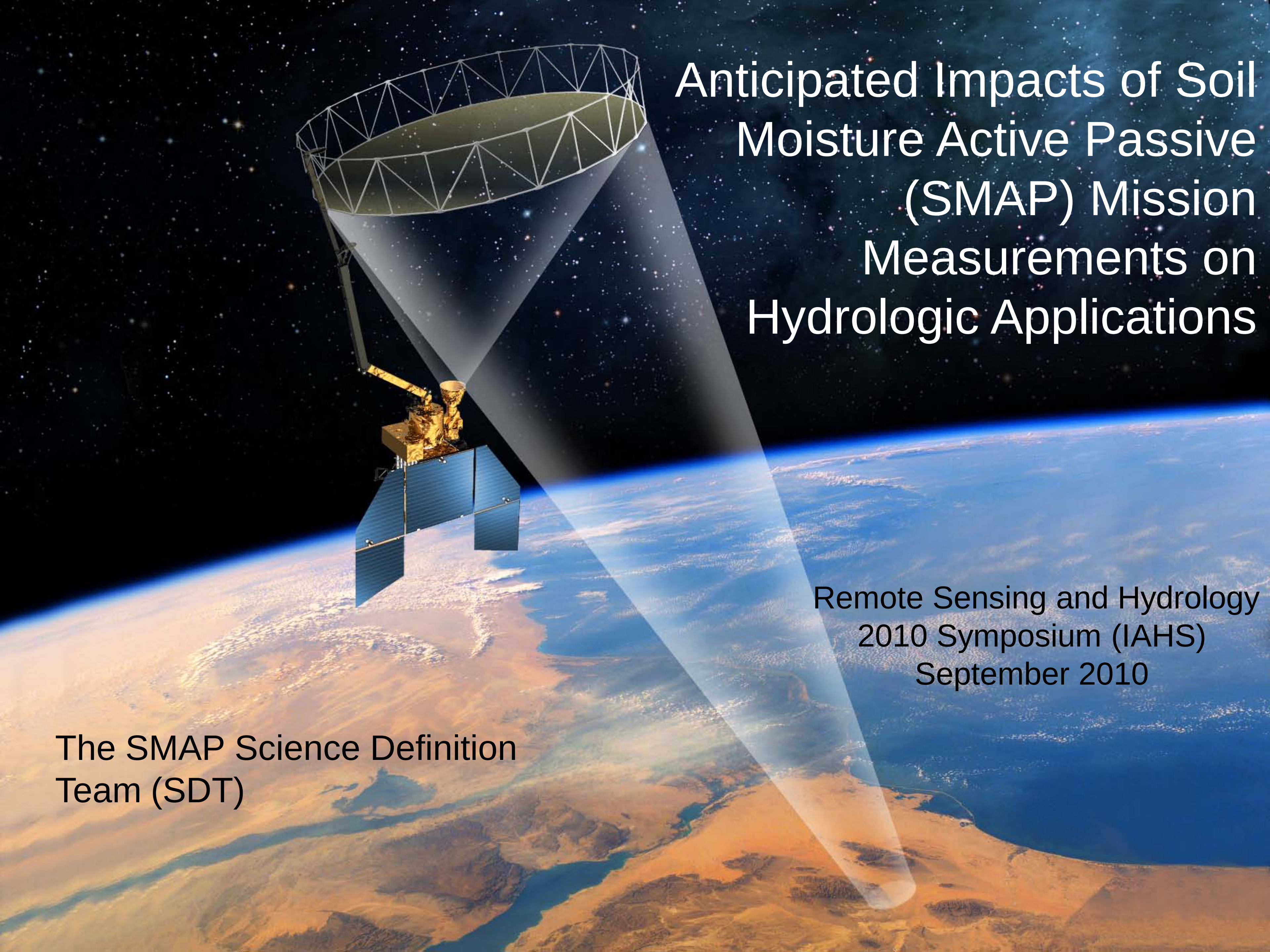
Anticipated Impacts of Soil Moisture Active Passive (SMAP) Mission Measurements on Hydrologic Applications



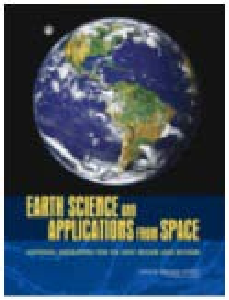
Remote Sensing and Hydrology 2010 Symposium (IAHS)
September 2010

The SMAP Science Definition Team (SDT)

Talk Outline

1. SMAP mission and the *Earth Science Decadal Survey*
2. Traceability of measurement requirements to hydrologic applications
3. Pathways of soil moisture influence on weather and climate
4. Applications to:
   - Drought monitoring and seasonal climate prediction
   - Water availability from snowmelt outlooks
   - Flood monitoring and forecasting
5. Data products and latencies

Project/Mission Overview—Mission Context



US National Research Council Report: "Earth Science and Applications from Space: National Imperatives for the next

SMAP is one of four missions recommended by the NRC "Decadal Survey" for launch in the 2010–2013 time frame

Tier 1: 2010–2013 Launch	
	Soil Moisture Active Passive (SMAP)
	ICESAT II
	DESDynI
	CLARREO
Tier 2: 2013–2016 Launch	
	SWOT
	HYSPIRI
	ASCENDS
	GEO-CAFE
	ACE
Tier 3: 2016–2020 Launch	
	LIST
	PATH
	GRACE-II
	SCLP
	GACM
	3D-WINDS

- Feb 2008: NASA announces start of SMAP project
- SMAP is a directed-mission with heritage from Hydros
- Hydros risk-reduction performed during Phase A (instrument, spacecraft dynamics, science, ground system) Cancelled 2005 due to NASA budgetary constraints

Science Requirements

DS Objective	Application	Science Requirement
Weather Forecast	Initialization of Numerical Weather Prediction (NWP)	Hydrometeorology
Climate Prediction	Boundary and Initial Conditions for Seasonal Climate Prediction Models	Hydroclimatology
	Testing Land Surface Models in General Circulation Models	
Drought and Agriculture Monitoring	Seasonal Precipitation Prediction	Hydroclimatology
	Regional Drought Monitoring	
	Crop Outlook	
Flood Forecast Improvements	River Forecast Model Initialization	Hydrometeorology
	Flash Flood Guidance (FFG)	
	NWP Initialization for Precipitation Forecast	
Human Health	Seasonal Heat Stress Outlook	Hydroclimatology
	Near-Term Air Temperature and Heat Stress Forecast	Hydrometeorology
	Disease Vector Seasonal Outlook	Hydroclimatology
	Disease Vector Near-Term Forecast (NWP)	Hydrometeorology
Boreal Carbon	Freeze/Thaw Date	Freeze/Thaw State

Requirement	Hydro-Meteorology	Hydro-Climatology	Carbon Cycle	Baseline Mission	
				Soil Moisture	Freeze/Thaw
Resolution	4–15 km	50–100 km	1–10 km	10 km	3 km
Refresh Rate	2–3 days	3–4 days	2–3 days(1)	3 days	2 days(1)
Accuracy	4–6% **	4–6%**	80–70%*	4%**	80%*

(*) % classification accuracy (binary Freeze/Thaw)

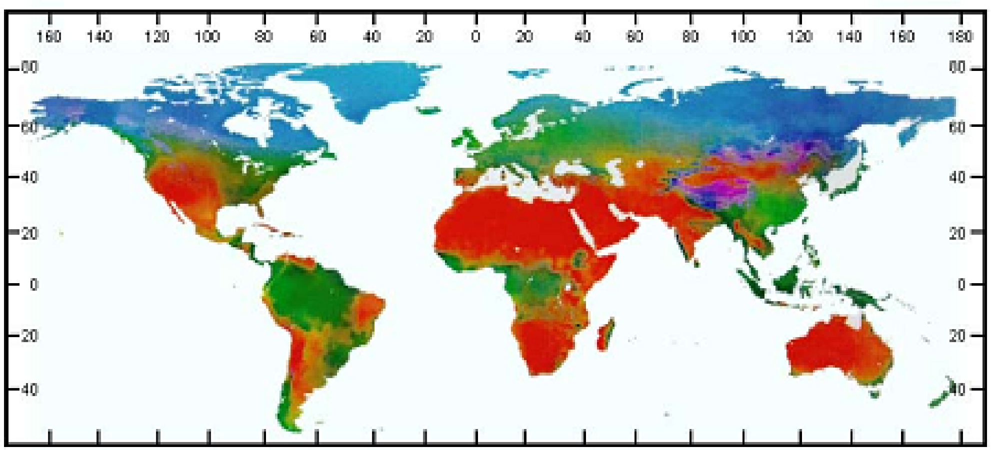
(**) [cm^3 cm^{-3}] volumetric water content, 1-sigma

(1)North of 45N latitude

Mission Science Objective

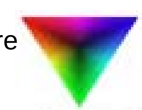
Global mapping of Soil Moisture and Freeze/Thaw state to:

- Understand processes that *link* the terrestrial water, energy & carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- *Enhance weather and climate forecast skill*
- *Develop improved flood prediction and drought monitoring capability*



Primary Controls on Land Evaporation and Biosphere Primary Productivity

Soil Moisture



Freeze/ Thaw

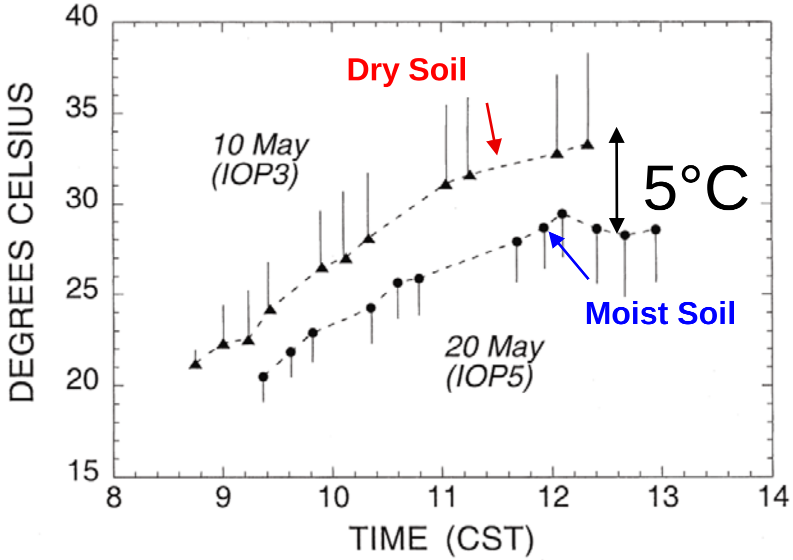
Radiation

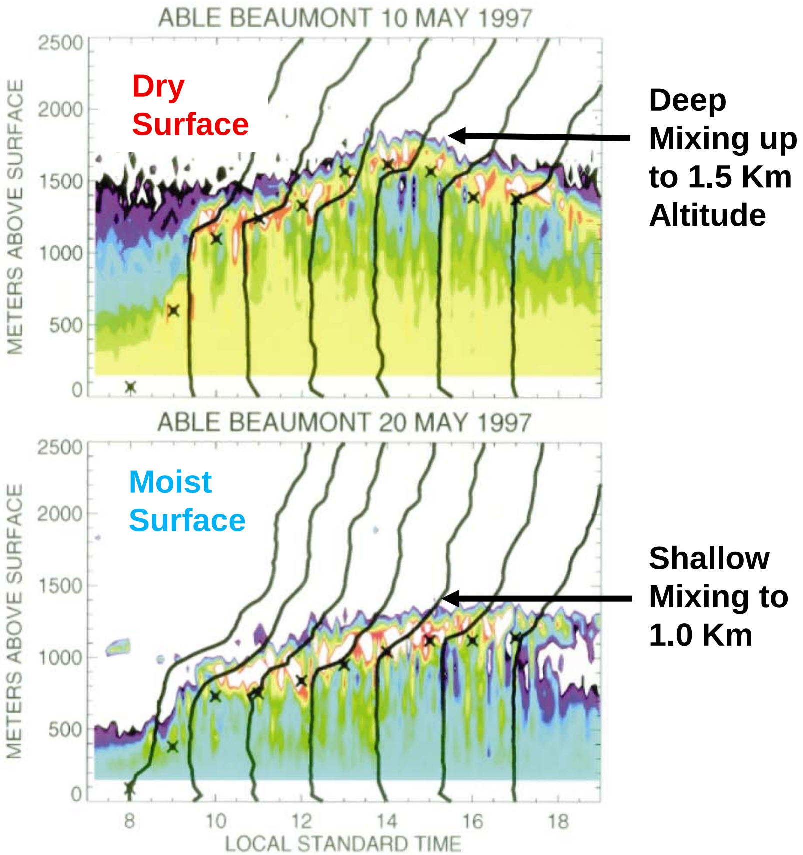
Pathways of Land Surface Influence on Weather and Climate

May 10 Dry soil, clear, mild winds. (**LE≈H**)

May 18 90 mm Rain

May 20 Moist soil, clear, mild winds. (**LE>H**)

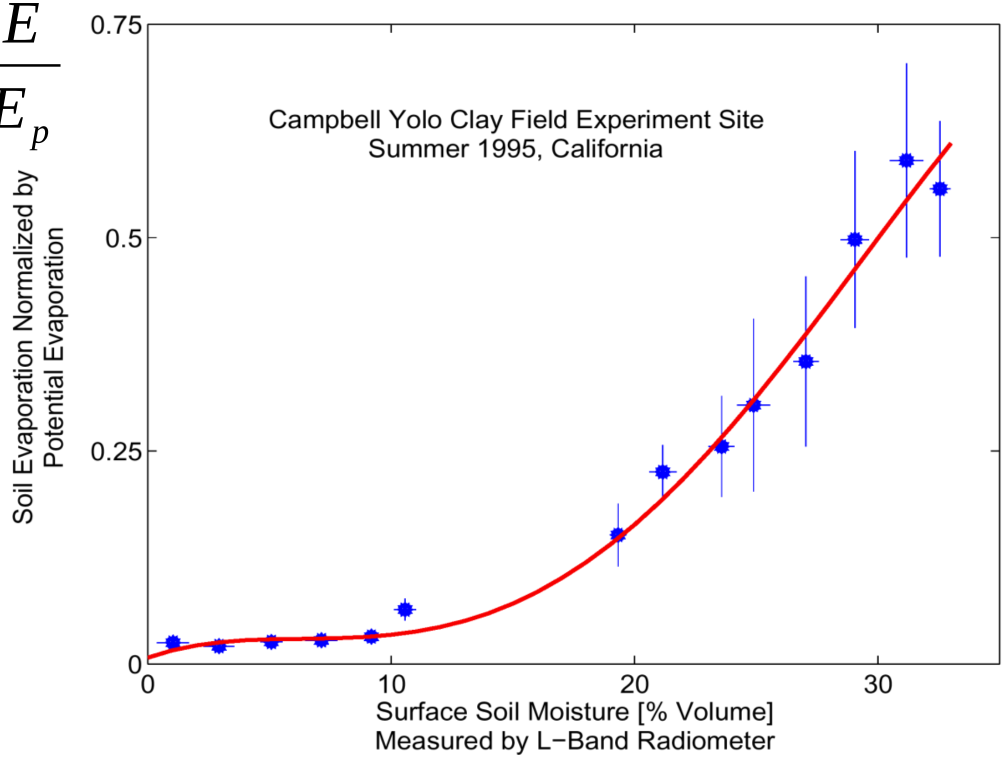




CASES'97 Field Experiment, *BAMS*, 81(4), 2000.

Key Determinants of Land Evaporation

$$\beta = \frac{E}{E_p}$$



Source: Cahill et al., *J. Appl. Met.*, 38

Latent heat flux (evaporation) *links* the water, energy, and carbon cycles at the surface.

Closure relationship, yet virtually unknown.

Lack of knowledge of soil moisture control on evaporation causes uncertainty in land surface and atmospheric models.

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What Do We Do Today?

NOAH

model grid cell and

$$\beta = \left(\frac{\Theta_1 - \Theta_w}{\Theta_{\text{ref}} - \Theta_w} \right)^f \qquad (7)$$

represents a normalized soil moisture availability term where Θ_w is the wilting point and Θ_{ref} is the field capac-

CLM

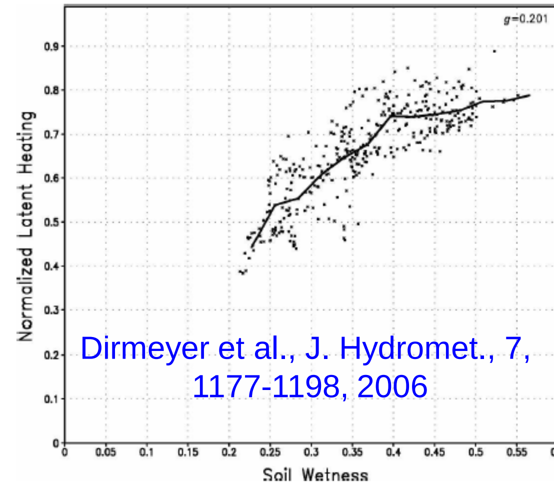
functional type and the soil water potential of each soil layer

$$\beta_t = \sum_i w_i r_i \geq 1 \times 10^{-10} \qquad (8.10)$$

where w_i is a soil dryness or plant wilting factor for layer i, and r_i is the fraction of roots in layer i.

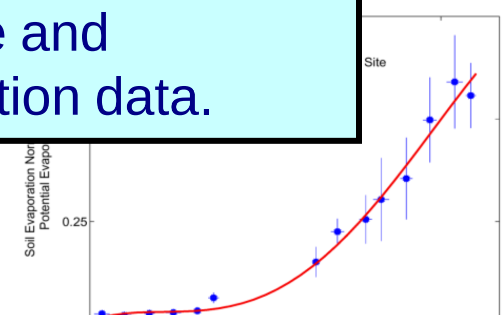
The plant wilting factor w_i is

$$w_i = \begin{cases} \dfrac{\psi_{\max} - \psi_i}{\psi_{\max} + \psi_{sat,i}} & \text{for } T_i > T_f \\ 0 & \text{for } T_i \leq T_f \end{cases} \qquad (8.11)$$



Dirmeyer et al., J. Hydromet., 7, 1177-1198, 2006

Atmospheric model representations of this function are essentially “guesses”, given scarcity of soil moisture and evaporation data.



Identification of Drought

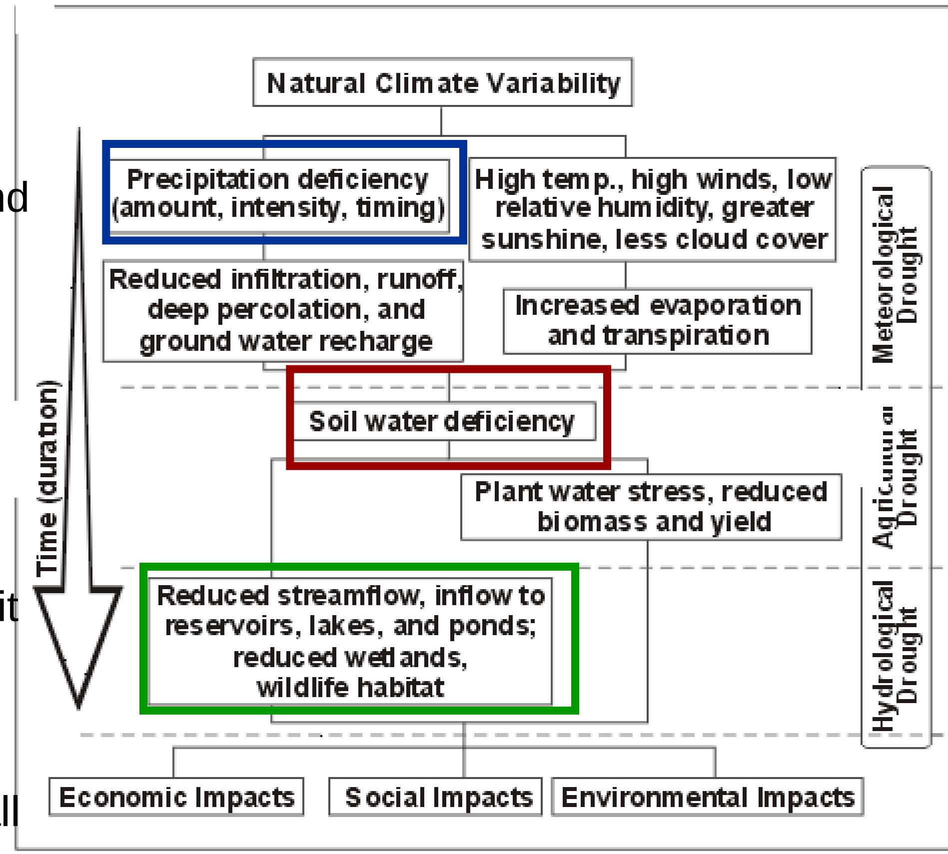
American Meteorological Society (AMS) Statement

Drought is often grouped into four basic types: 1) meteorological, 2) agricultural, 3) hydrological, and 4) socioeconomic.

Meteorological drought … magnitude [and duration] of a precipitation shortfall

Agricultural drought is largely the result of a deficit of soil moisture…

Hydrological droughts are concerned with shortfall on surface or subsurface water supply…Rootzone, vegetation and streams response



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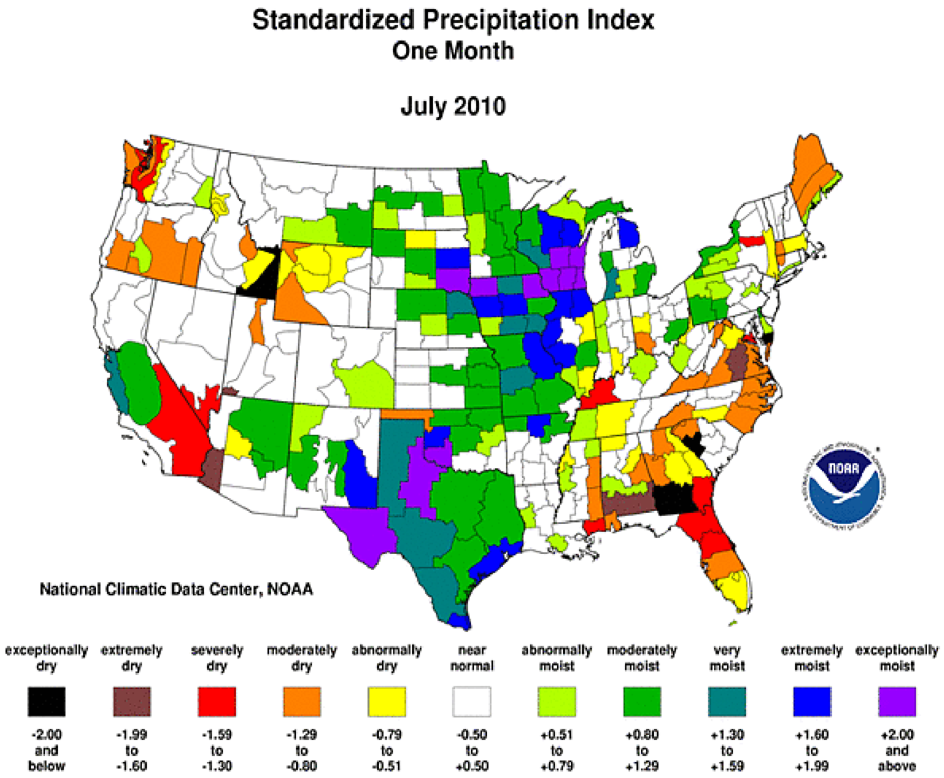
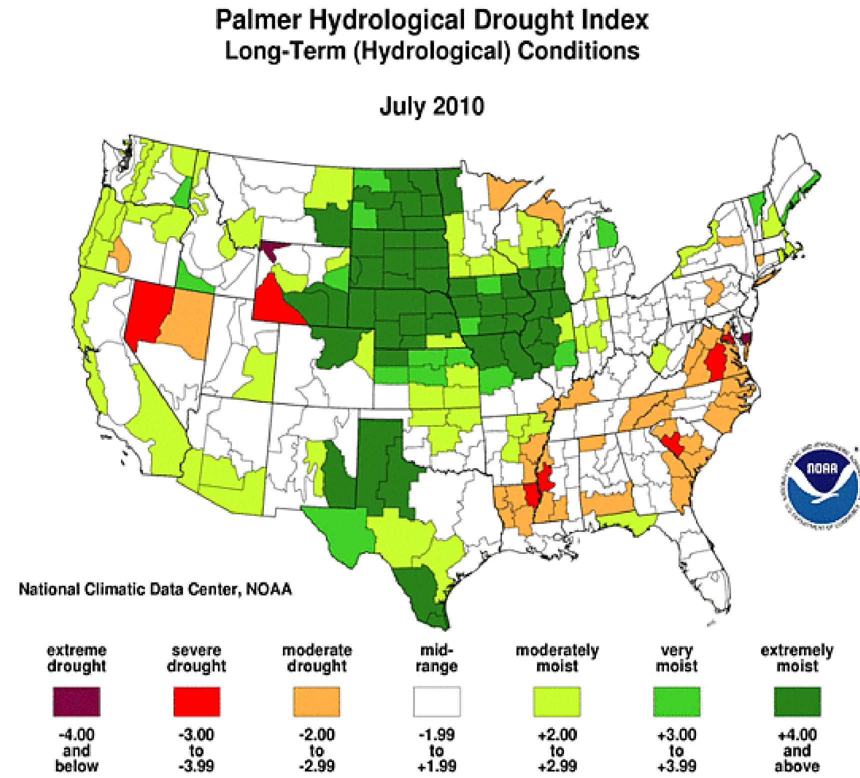
Drought and Soil Moisture

Agricultural drought (deficit of soil moisture) cannot necessarily be inferred from precipitation deficit.

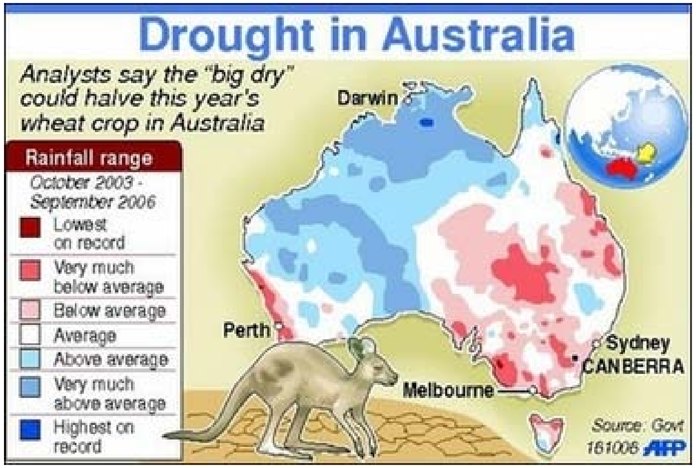




The Standardized Precipitation Index (SPI) for July 2010.

Palmer Drought Severity Index (PDSI) for July 2010.

Role of Root-Zone Soil Moisture in Drought Duration and Climate Change Impacts



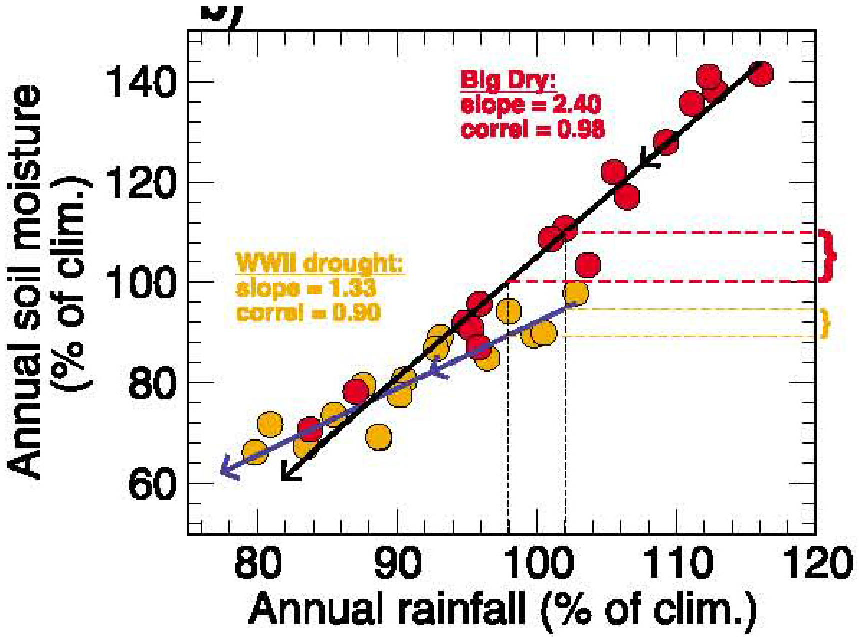
Root-zone soil moisture dynamics may contribute to prolonged drought conditions.

Conditions are similar to those expected under global change.

Cai et al., 2009: Rising temperatures depletes soil moisture and exacerbates severe drought conditions across southeast Australia, *Geophy. Res. Letters*, 36.

"Compared with the WWII drought, multi-year averages of rainfall and subsurface soil moisture during the Big Dry are not as low, but the sensitivity of soil moisture to rainfall decline is over 80% higher.

We show that a relationship exists between subsurface soil moisture variations and fluctuations of temperature not associated with rainfall over eastern Australia in all seasons, and over SEA in austral spring and summer. "



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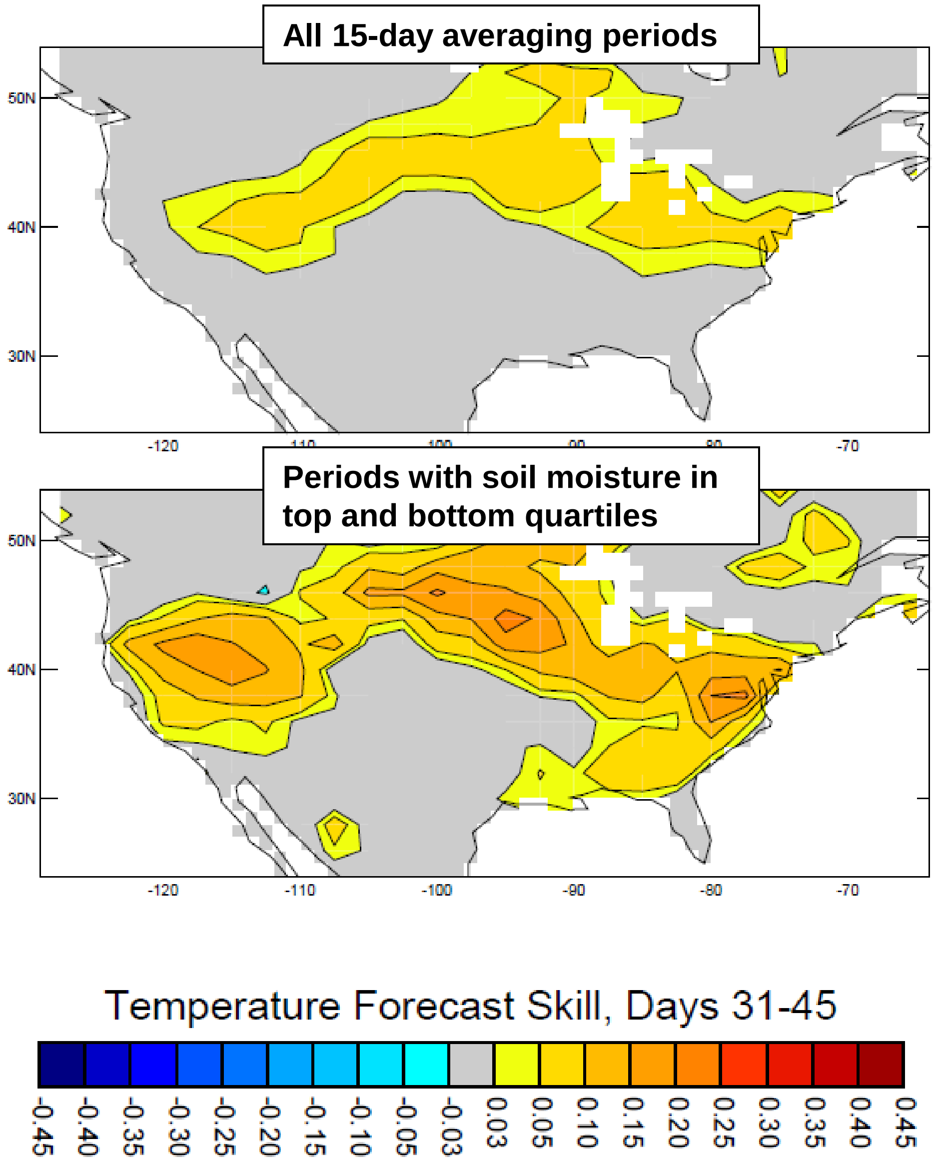
Seasonal Climate Prediction



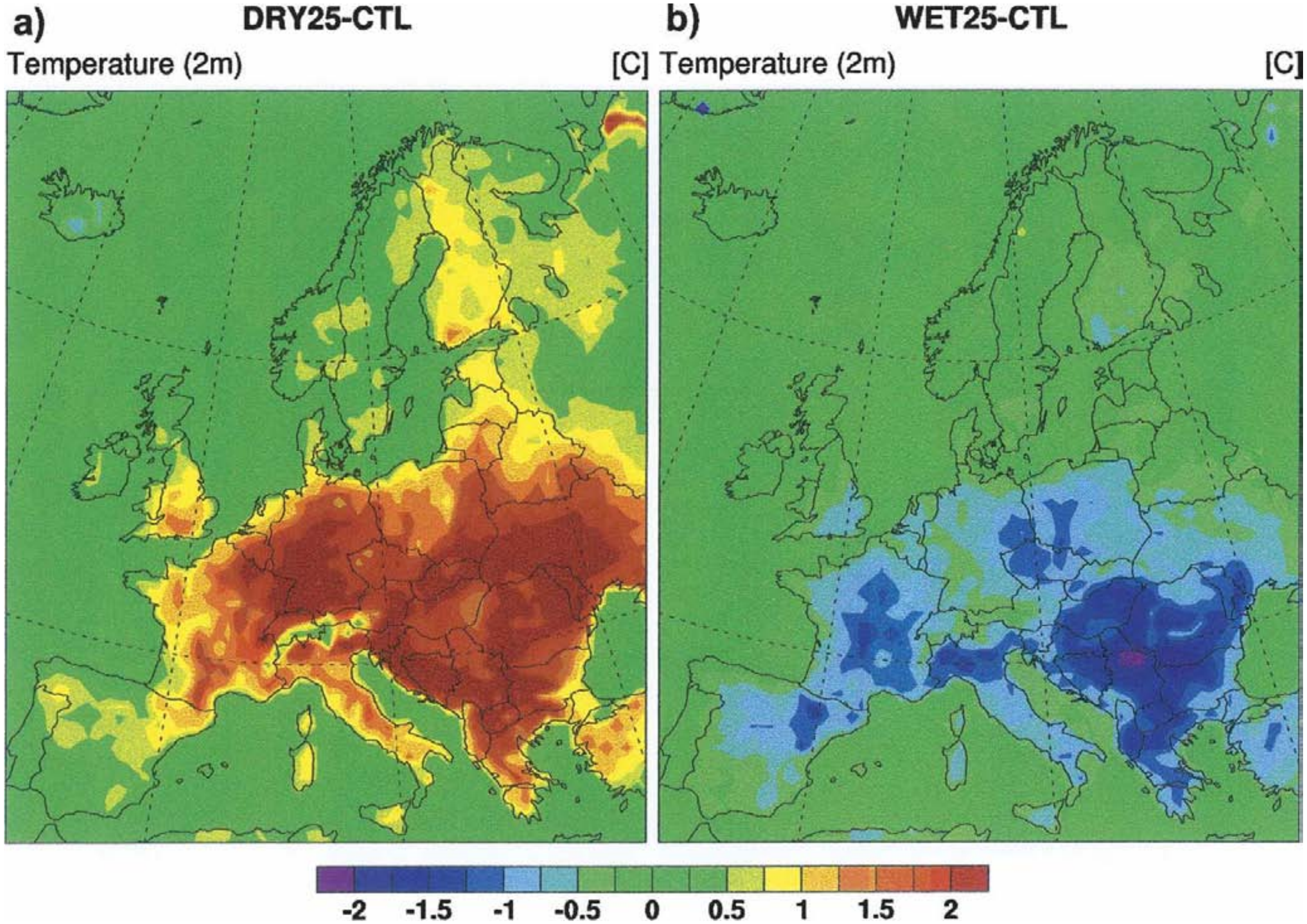
Multi-model consensus view of land contribution to air temperature forecasts.

JJA Skill contribution at the 30-day lead (days 31-45).

<u>From</u>: Final Report of GLACE-2: Quantifying the Effects of Land Moisture Initialization on Precipitation Forecasts (PI: Randal Koster, 2010)

Seasonal Climate Prediction

European heatwave cause
35,000 deaths,
New Scientist, Oct. 2003.



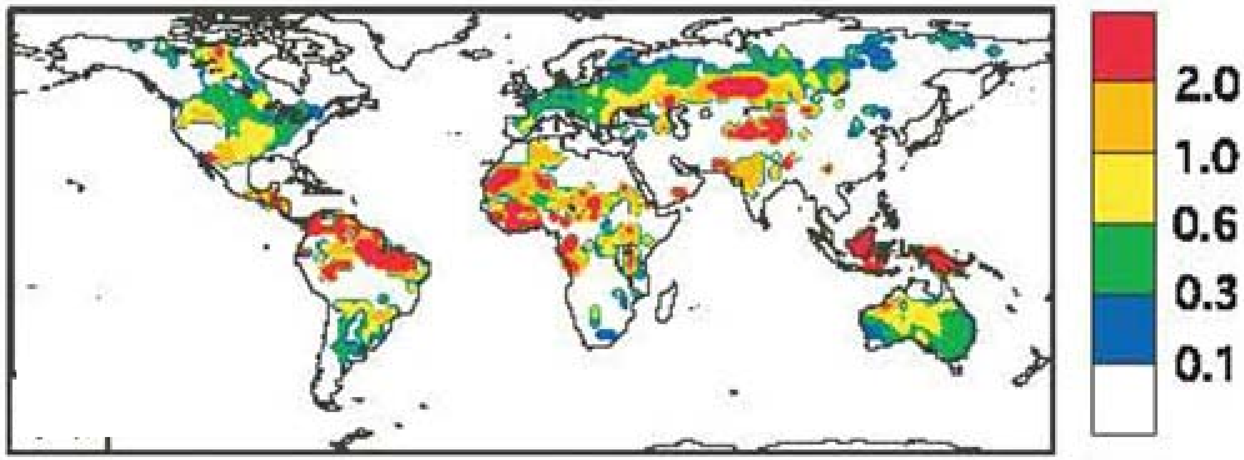
<u>Seasonal Climate Prediction</u>:
50 km Resolution
Initialize rootzone moisture

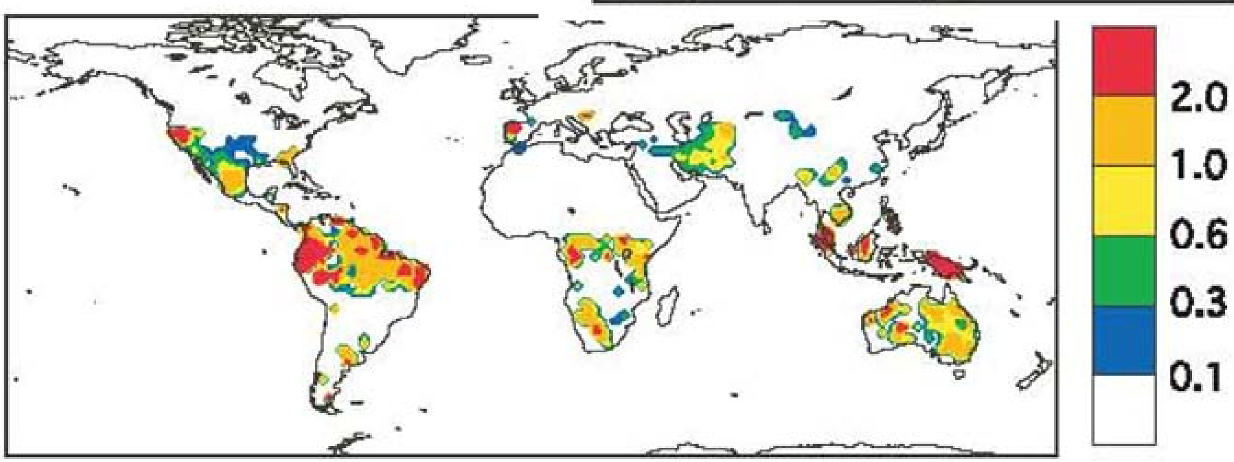
Fischer et al. (2007), *J. of Climate*, 20.

Global Change and Water Cycle

Future Climate and Water Cycle: Soil moisture influence on precipitation intensifies the regional water cycle response to global change.

Mean Summer (JJA) soil moisture feedback parameter on precipitation among 19 IPCC models [cm/month]





Same for Winter (DJF)

Global average monthly precipitation over land is ~8 cm/month

Notaro, M., 2008: Statistical identification of global hot spots in soil moisture feedback among IPCC AR4 models, *J. Geophys. Res*., 113.

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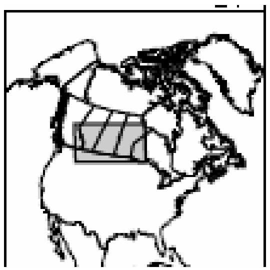
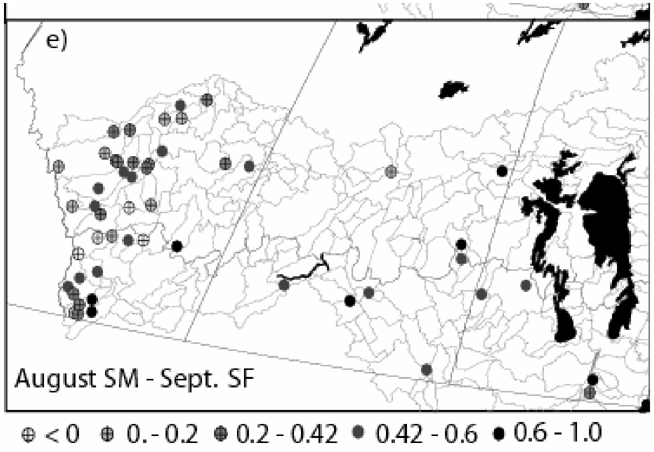
Water Availability from Snowmelt

Soil moisture information can contribute skill to streamflow forecasts

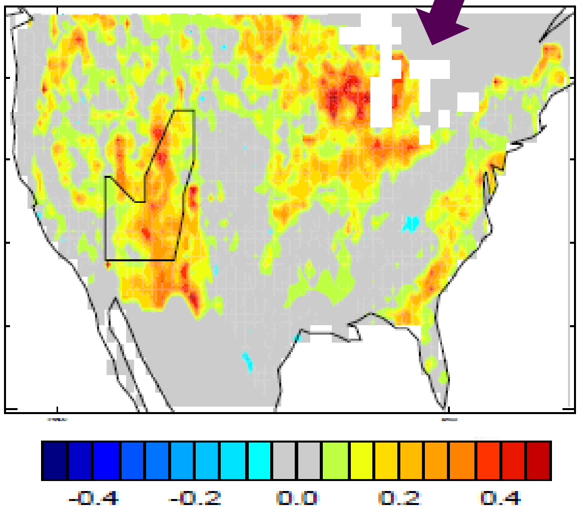
Linear regression analysis examining observed streamflow, snow, climate and soil moisture:



"This study demonstrates that available macroscale estimates of soil moisture have the potential to enhance streamflow prediction..."
(Berg and Mulroy, Hydro. Sci., 51, 642-654, 2006)



Contribution (r^2) of Jan. 1 soil moisture initialization to MAM streamflow prediction.



Synthetic analysis showing where soil moisture initialization may improve streamflow prediction at seasonal timescales. Results are supported by available streamflow observations.
(Mahanama et al., in preparation)

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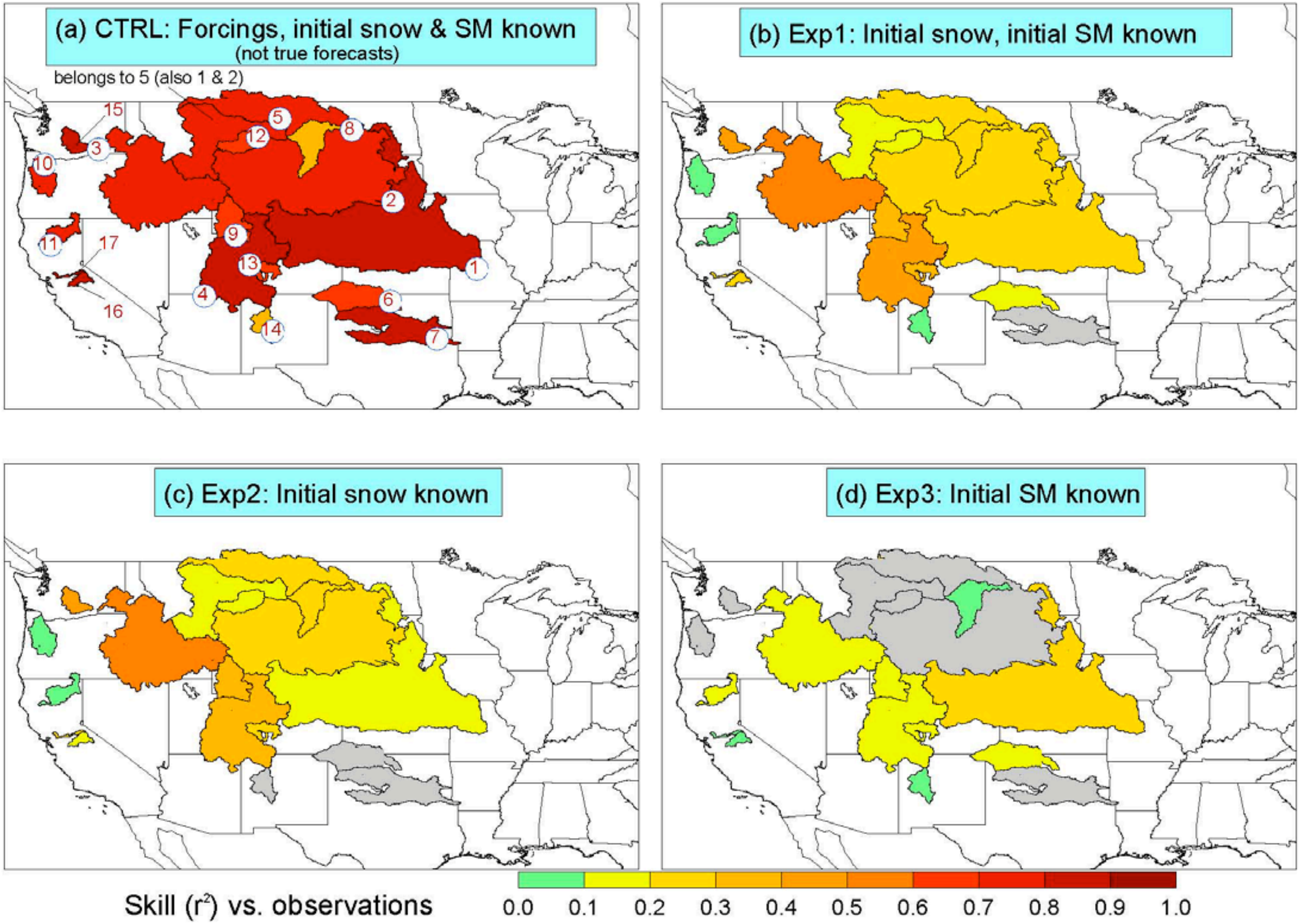
Soil Moisture Information Enhances Water Resource Availability Predictions

Koster et al., 2010: Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow", *Nature-Geoscience*, in press.

May-July streamflow forecasts



Flood Applications: The Forecast and Monitoring Chain

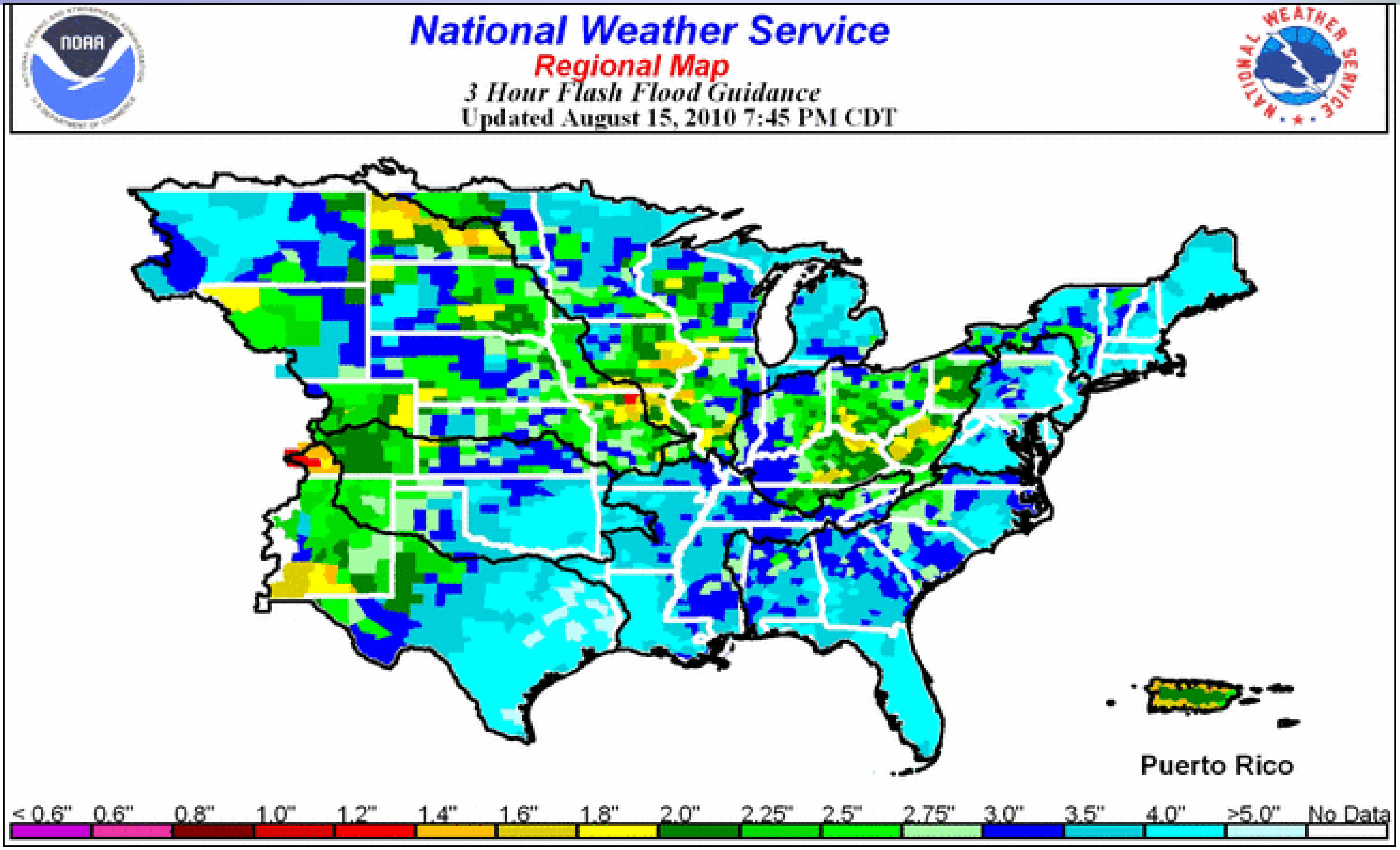
1) Characterization of pre-storm soil moisture

2) Accurate real-time rainfall monitoring (in large basins)

3) Numerical weather prediction of extreme rainfall

4) Monitoring inundation

Characterization of Pre-Storm Soil Moisture



Current: Empirical soil moisture indices based on filtering precipitation time-series at county resolution (~50 km)

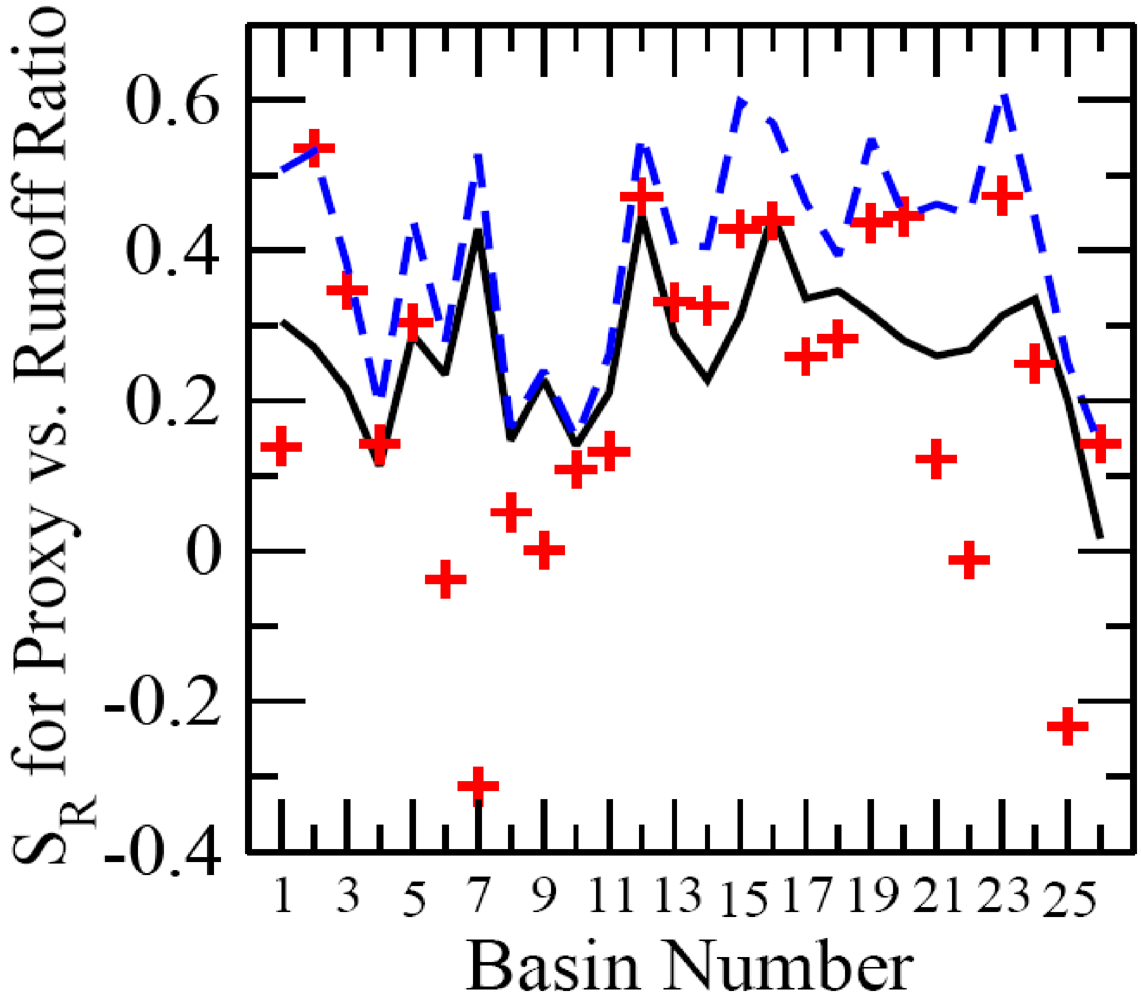
Future: Direct observations: SMAP at 10 km

Characterization of Pre-Storm Soil Moisture

Red – Remote Sensing Only (TRMM TMI)

Black – Model Only

Blue – Remote Sensing/ Model KF Combined



(>30^2 km^2 MOPEX Basins in Southern US)

Characterization of Pre-Storm Soil Moisture

Red – Remote Sensing Only (TRMM TMI)

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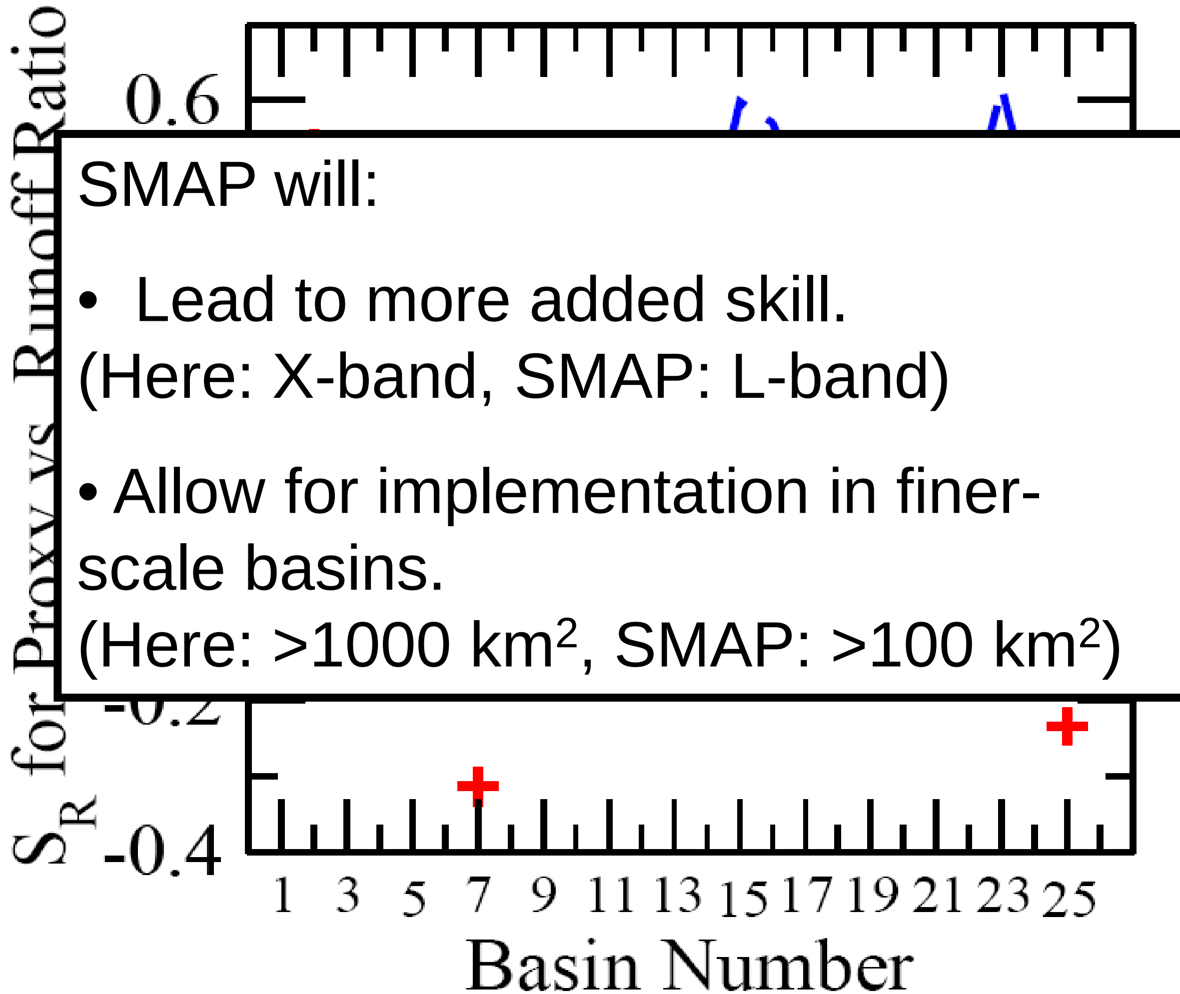

SMAP will:

- Lead to more added skill.

(Here: X-band, SMAP: L-band)

- Allow for implementation in finer-scale basins.

(Here: >1000 km^2, SMAP: >100 km^2)

(>30^2 km^2 MOPEX Basins in Southern US)

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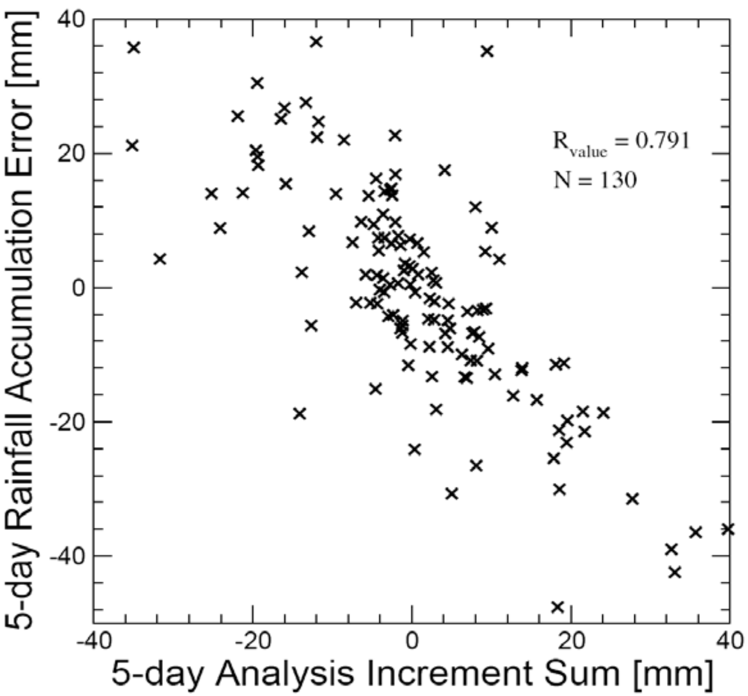
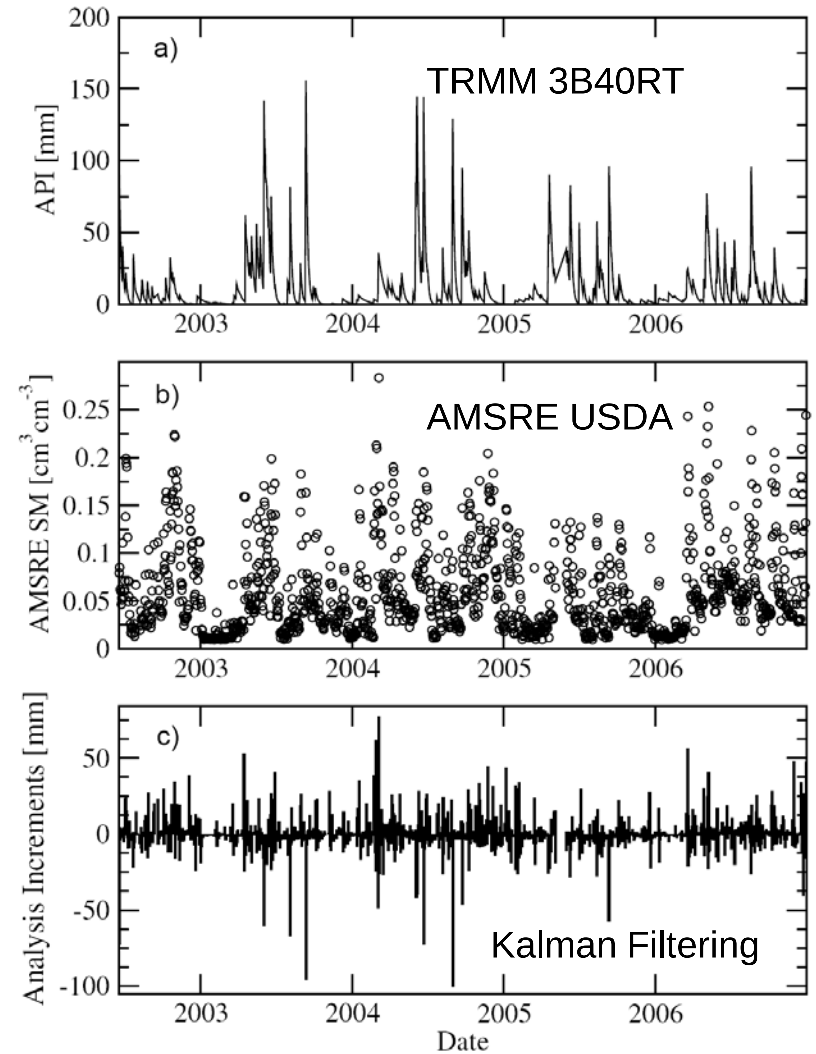
Accurate Rainfall Monitoring

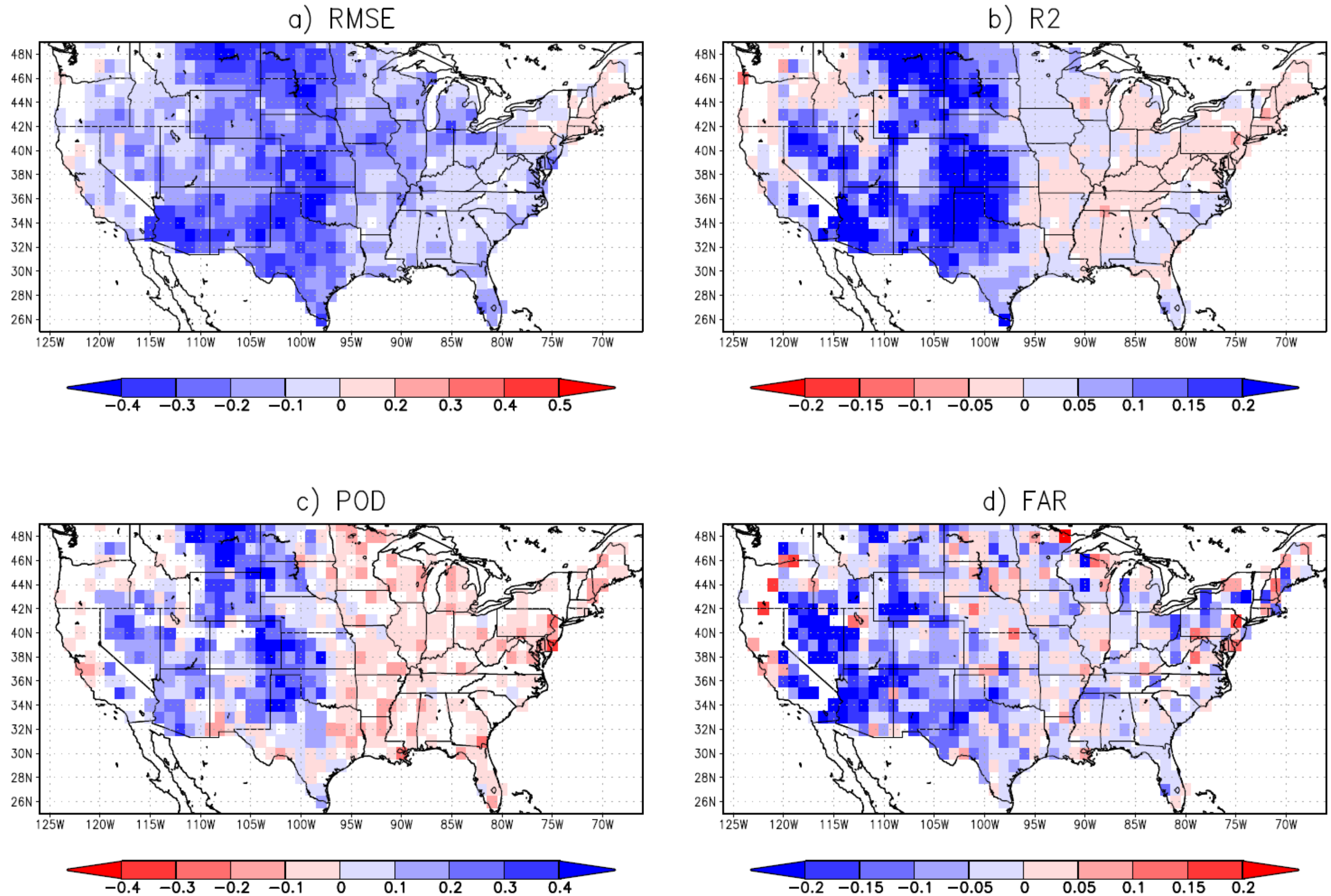
Crow et al. (2009), JHM, 10(1), 199-212.





Accurate Rainfall Monitoring

Improvement in TRMM 3B40RT 3-day accumulation skill



Crow et al. (2009), JHM, 10(1), 199-212.

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Accurate Rainfall Monitoring

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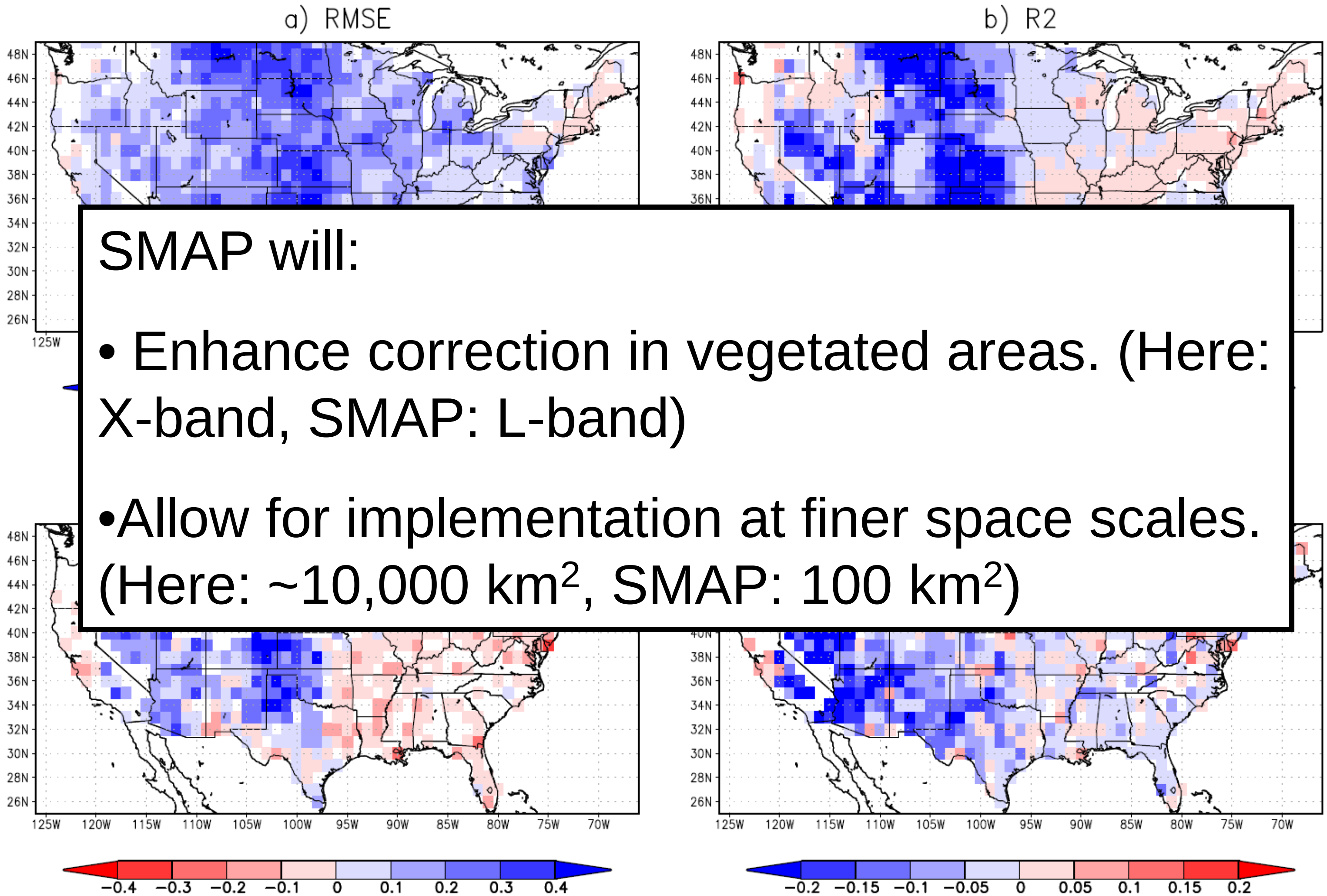


SMAP will:

- Enhance correction in vegetated areas. (Here: X-band, SMAP: L-band)

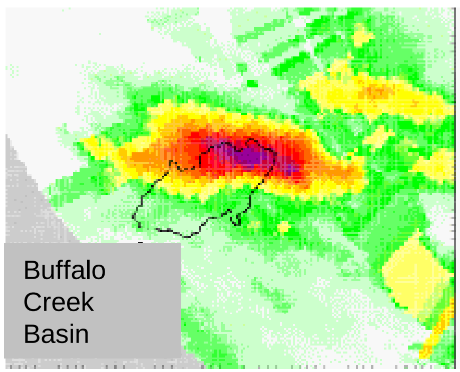
- Allow for implementation at finer space scales. (Here: ~10,000 km^2, SMAP: 100 km^2)

Crow et al. (2009), JHM, 10(1), 199-212.

Prediction of Extreme Rainfall

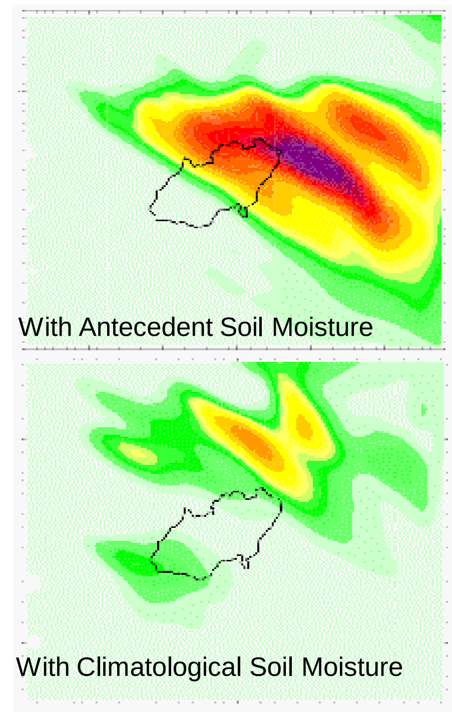
Flash flood event near Fort Collins
July 13, 1996

Chen et al. (2001), *JAS*, 58, 3204-3223.

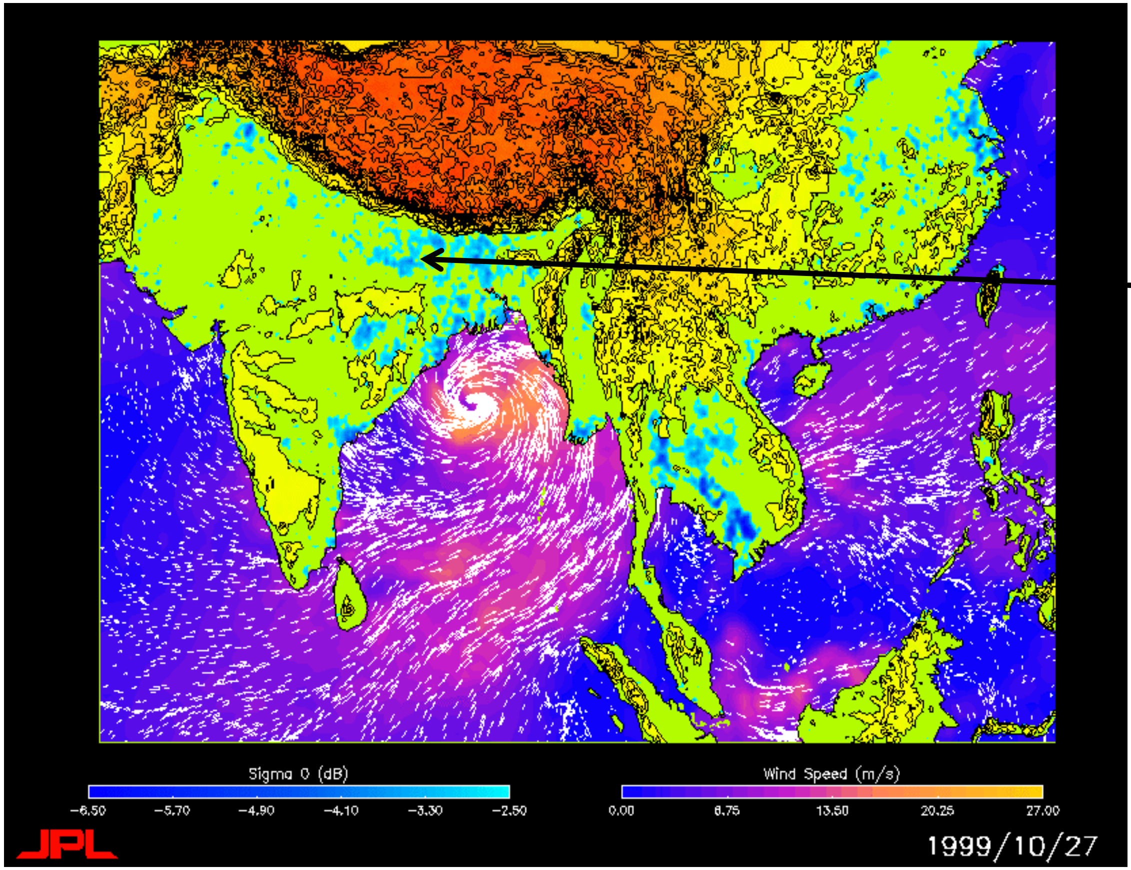


NEXRAD Observed Rainfall
0000Z to 0400Z 13/7/96

24-Hours ahead
atmospheric model
forecasts



Monitoring Inundation



Inundation detection using dual-polarization QuikSCAT backscatter data. Shades of blue on land represent inundation

[Form Son Nghiem, JPL]

$$\gamma = \frac{\sigma_{vv}}{\sigma_{hh}}$$

SMAP provides 3 km resolution dual-polarization radar data with 2-3 days revisit (all-weather and regardless of illumination)

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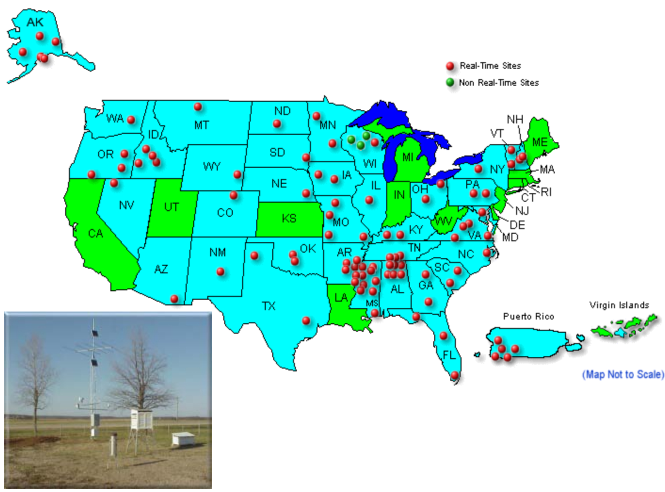
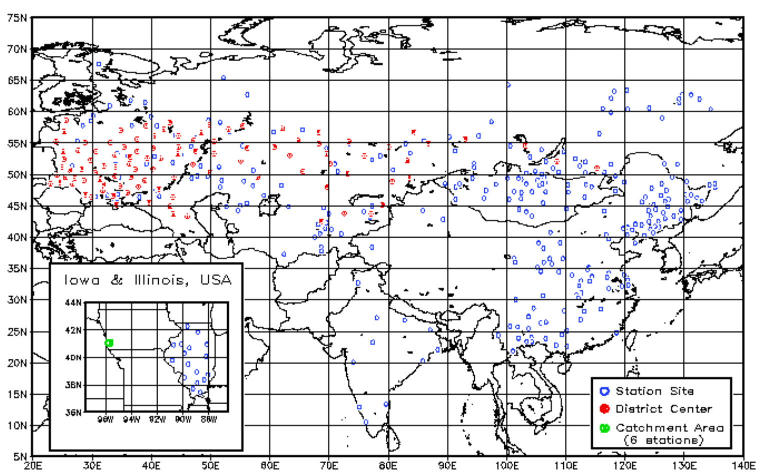
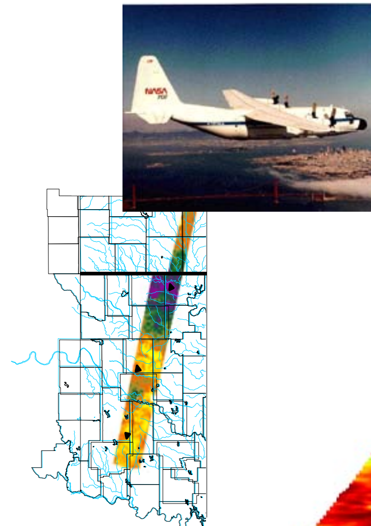
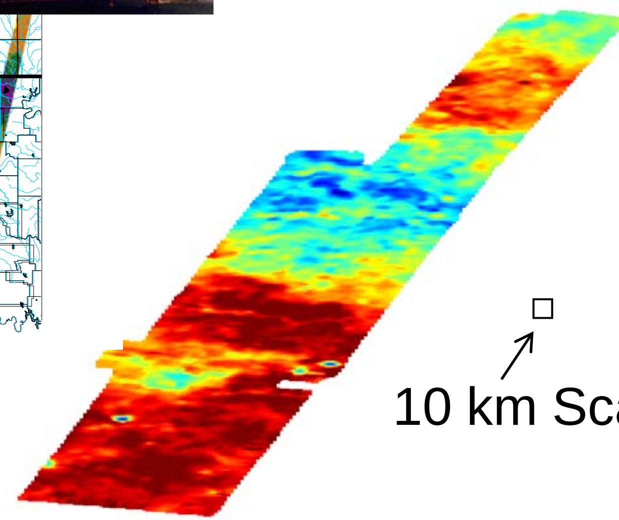
In situ Soil Moisture Network Coverage:Adequate?







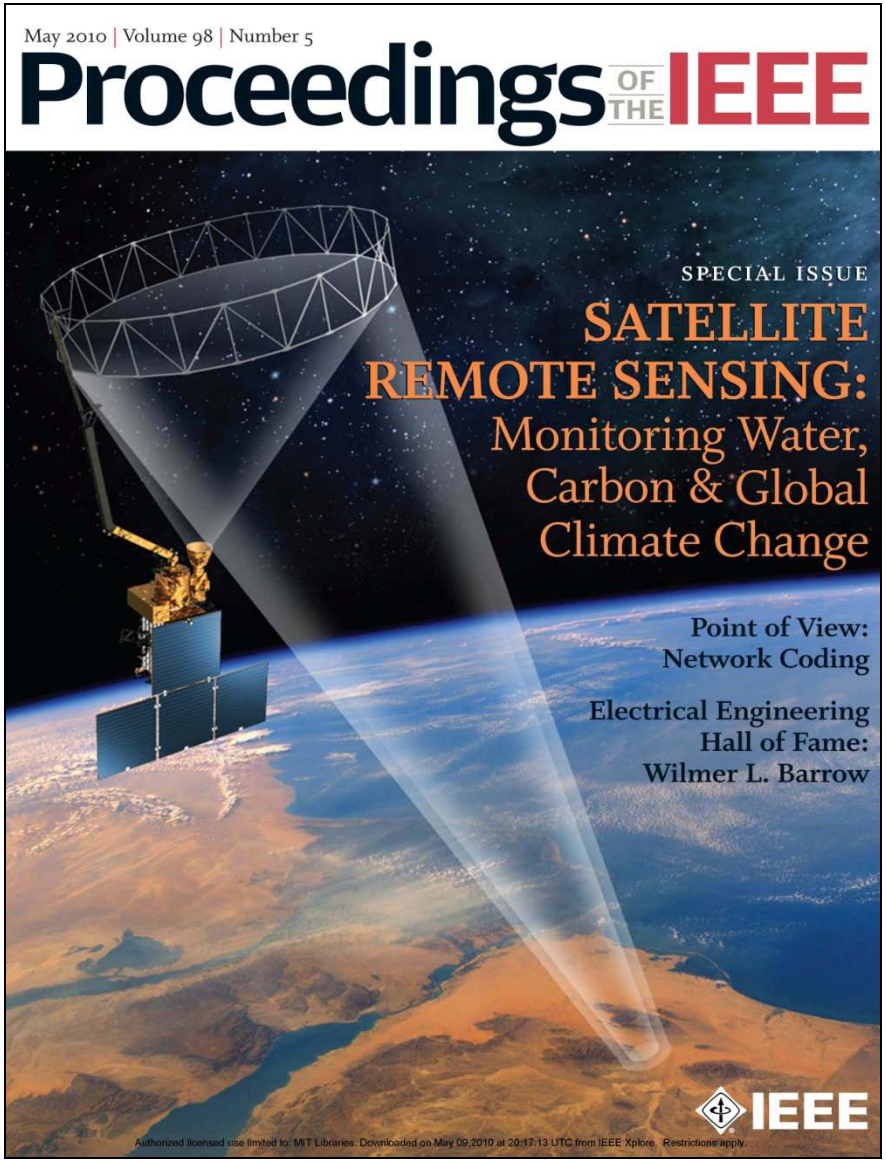
An airborne campaign
US SGP



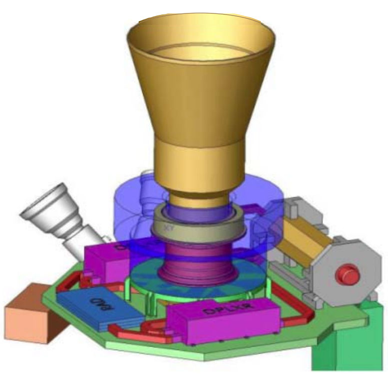
10 km Scale

Significant spatial variability between point measurements !

SMAP Mission Concept



- L-band unfocused SAR and radiometer system, offset-fed 6 m light-weight deployable mesh reflector. Shared feed for
  - 1.26 GHz dual-pol <u>Radar</u> at 1-3 km (30% nadir gap)
  - 1.4 GHz polarimetric <u>Radiometer</u> at 40 km
- Conical scan, fixed incidence angle across swath
- Contiguous 1000 km swath with 2-3 days revisit
- Sun-synchronous 6am/6pm orbit (680 km)
- Launch November 2014
- Mission duration 3 years



L-band Active/Passive Assessment

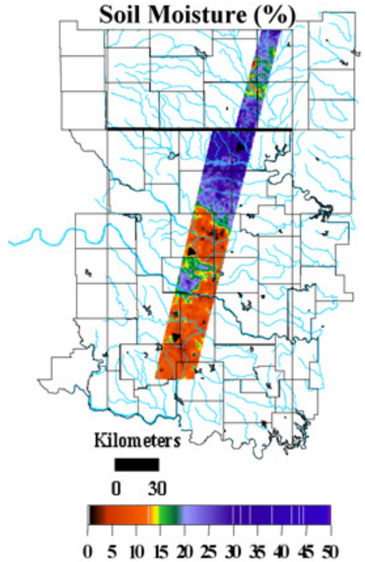
- Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments

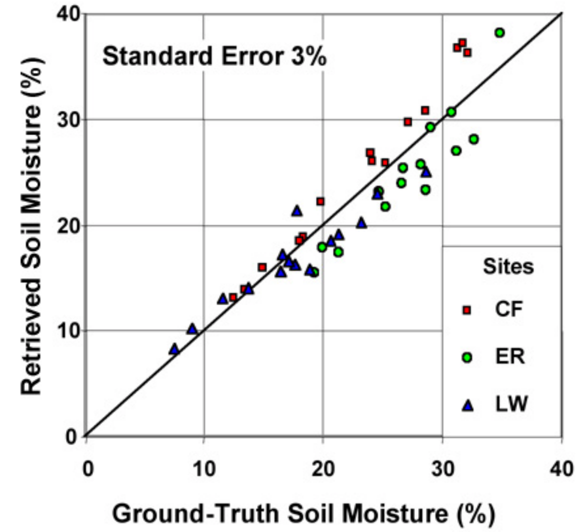
  MacHydro’90, Monsoon’91, Washita92, Washita94, SGP97, SGP99, SMEX02, SMEX03, SMEX04, SMEX05, CLASIC, SMAPVEX08, CanEx10

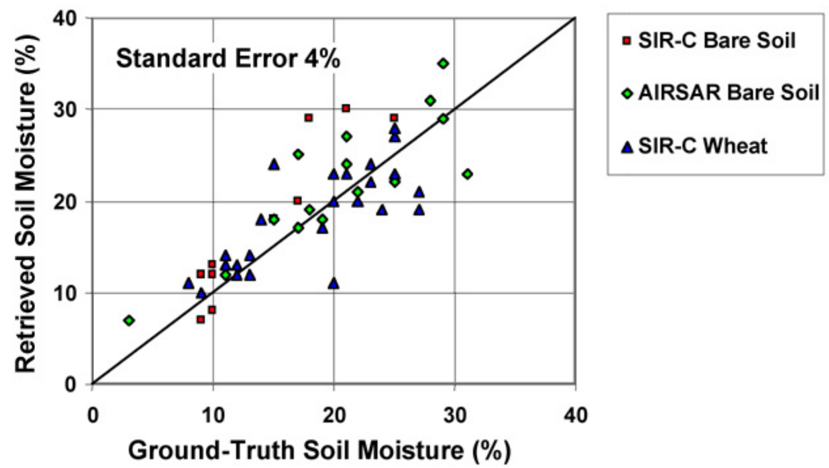
- ***Radiometer*** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)

- ***Radar*** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation

- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science objectives







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SMAP Data Products

Product	Short Description	Resolution	Latency	
L1A_S0	Radar raw data in time order	–	12 hours	Instrument Data
L1A_TB	Radiometer raw data in time order	–	12 hours	
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	12 hours	
L1B_TB	Radiometer T_B in time order	36x47 km	12 hours	
L1C_S0_HiRes	High resolution radar σ_o	1-3 km	12 hours	
L1C_TB	Radiometer T_B	36 km	12 hours	
L2_SM_A	Soil moisture (radar)	3 km	24 hours	Science Data (Half-Orbit)
L2_SM_P	Soil moisture (radiometer)	36 km	24 hours	
L2_SM_A/P	Soil moisture (radar/radiometer)	9 km	24 hours	
L3_F/T_A	Freeze/thaw state (radar)	3 km	36 hours	Science Data (Daily Composite)
L3_SM_P	Soil moisture (radiometer)	36 km	36 hours	
L3_SM_A/P	Soil moisture (radar/radiometer)	9 km	36 hours	
L4_SM	Soil moisture (surface & root zone)	9 km	7 days	Science Value-Added
L4_C	Carbon net ecosystem exchange (NEE)	9 km	14 days	

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